

The observation of the Earth Radiation Budget a set of challenges

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Metrology in space, W/m^2 (*)

Budget = Incident – Reflected - Emitted)

Sun, easy

Quasi constant,
Easy sampling,
Small angular extension,

Total Solar Irradiance

ACRIM, PMO6, ERBE, DIARAD,
In agreement.
TIM measures less , why ?

Earth, difficult (*)

High variability in space and time (*)
and colours, (*)
Difficult sampling, (*)
Large angular extension,

Reflected solar total flux, (*)
Emitted Infrared total flux (*)

Nimbus 6&7, ERBE, Scarab, CERES,
GERB



The sampling

Polar orbits, synchronous
and drifting

Global Earth,
poor temporal sampling (*)

Each place seen once *every 12h*,

Climate application at those times

Four satellites required for
3 hour periodic observations

Geostationary orbit

Partial Earth, (*)
Good temporal sampling,

Each place measured *every 5 min*

Climate local, regional,
Atmospheric physics,
Meteorology

Three satellites required to
cover full Earth at Equator,
more for overlapping



Coherence of all observations

Polar and geostationary observations are complementary

To cover the full Earth also at the poles,

To be able to compare observation results and identify the reason of differences (*), and find required adjustments(*)

The results at the same conditions should be identical

But this is not sufficient to prove accuracy ! (*)

Necessary to determine a maximum of Angular Direction Models (ADM)



Observation instruments

On polar orbits

Flat plate radiometer (*no mirror*),

Cosine response, (*)

Spectral response of black coating, (*)

Time response (*)

Absolute or calibrated (aging) (*)

Measures flux at satellite altitude,
(variability diminishes with altitude)

Medium field of view radiometer
(not interesting)

Black or reflective spheric satellite
with triaxial Accelerometer
(original concept by ONERA)

Scanning telescopes (*two mirrors*)

Point spread function, (*)

Spectral response, (*)

Time response (*)

Calibration (aging) (*)

Measures filtered radiances (*)

Scanning across track (track width
function of altitude),

Scanning along track (ADM directrix),

Rotation scanning



Observation instruments

On geostationary orbits

Three axis stabilised satellite TBD , full observation time (Tom Vonderhaar historical proposal)

Spin stabilised satellite GERB (*five mirrors* due to space restriction)

Part of observation time is lost counter rotating mirror required to freeze scenery. (*)

Target location function of parallelism of GERB and MSG axis. (*)

Start of pulse jitter can not be corrected. (*)

Telescope point spread function (altitude) (*)

Spectral response for all pixels,(filtered radiances) (*)

Fast response time required (*)

Note: MSG rotates at 100 rev/min, GERB submitted to 18 G ! (*)



Filtered radiances spectral corrections

Required

Instrument spectral characterisation, (*)

Space aging (*)

Target localisation with Imager (MODIS, SEVIRI, other)

Scenery, type, cloud fraction, optical depth identification, (*)



Radiances to irradiances transformation

Required

Instrument spectral characterisation, (*)

Instrument space aging (*)

Target localisation with Imager (MODIS, SEVIRI, other) (*)

Scenery, type, cloud fraction, optical depth, ADM identification, (*)

Radiance measurement footprint, imager space resolution, (*)

Satellite viewing geometry relative to target, solar zenith angle,

ADM specific to target. (*)



« To put the Earth into a calorimeter »

an international cooperation
and strategy
is required

(*)

based on different tactics
and methodologies

Focused on metrology
(associate flat plate radiometer to scanners)

(*)



References

Luis Gonzalez, "GGSPS Geolocation Assessment with RGP", Technical Note, 2003, Unpublished.

[BAMS] J.E. Harries et al. (2005):

The Geostationary Earth Radiation Budget Project, *Bulletin of American Meteorological Society*, **86**(7), 945-960, doi:10.1175/BAMS-86-7-945.

[ERBE] Taylor, V. R., and L. L. Stowe:

Reflectance characteristics of uniform Earth and cloud surfaces derived from Nimbus 7 ERB, *J. Geophys. Res.*, **89**, 4987– 4996, 1984.

[Loeb] Loeb, N.G., et al., 2003:

Angular distribution models for top-of-atmosphere radiative flux estimation from the Clouds and the Earth's Radiant Energy System instrument on the Tropical Rainfall Measuring Mission Satellite. Part I: Methodology, *J. Appl. Meteor.*, **42**:240–265.

[Ipe] A. Ipe, N. Clerbaux, C. Bertrand, S. Dewitte, L. Gonzalez (2003):

Pixel-scale composite top-of-the-atmosphere clear-sky reflectances for Meteosat-7 visible data, *Journal of Geophysical Research*, **108**(D19), 4612, doi:10.1029/2002JD002771.

[Ipe2] A. Ipe, N. Clerbaux, C. Bertrand, S. Dewitte, L. Gonzalez (2004):

Validation and homogenisation of cloud optical depth and cloud fraction retrievals for GERB/SEVIRI scene identification using Meteosat-7 data, *Atmospheric Research*, **72**, 17-37, doi:10.1016/j.atmosres.2004.03.010.

[CERES] Wielicki, B., Barkstrom, B.R., Harrison, E.F., Lee, R.B., Smith, G.L., Cooper, J.E., 1996. Clouds and the Earth's Radiant Energy System (CERES): an earth observing system experiment. *Bull. Am. Meteorol. Soc.*

77, 853– 868.



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The determination of the Earth Radiation Budget (ERB) and its terms are considered step by step to show the multiple challenges that need to be overcome.

They are mostly due to the high spatiotemporal, spectral and angular variability of the target, associated with the imperfect spectral integration of the radiation to be measured.

The necessary conversion of filtered radiances to total irradiances (fluxes) will require the best attention and constructive interaction of the different observation groups in view to be able to provide coherent Earth Radiation Budget data.

The ERB missions are by definition *group challenging metrological programs* because they involve different instruments used by different groups of actors in different space observation configurations; they are aimed to extract the net budget, of local, regional or global incident and outgoing (reflected and emitted) radiation of the Earth all to be expressed accurately *in W/m² !*

Two different targets are thus considered, a relatively easy one of small angular extension: the *Sun* origin of the incident radiation, and a very difficult one: the *Earth*, highly variable in space, time and colours.

For the Sun four independent measurements of the total solar irradiance made with DIARAD, PMO6, ACRIM and the ERBE Sun monitor agree within 0.1%, a fifth instrument TIM on SORCE, the most recent with a different servo system and data treatment approach, measures...W/m² less than the previous four. Up to now the reason of the difference has not been identified.

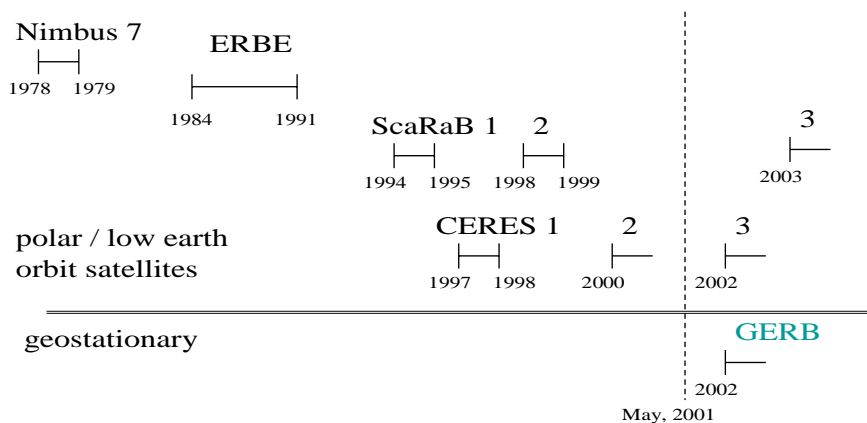
For the Earth the global observation of the ERB terms has been performed with Nimbus 6 & 7 followed in 1984 by LaRC with the ERBE and CERES [CERES] programs *from drifting and synchronous polar orbits* as also SCARAB. They provide *two observations per day*, twelve hours apart of each place on Earth,

suitable for global climate monitoring *at those times*, daily means are thus not measured with real diurnal variability patterns changing from place to place. Four satellites properly spaced would provide one observation of each place every 3 hours...

Since December 2002 observations from MSG with GERB [BAMS] are also made from *geostationary orbit*. It provides full spatial and temporal *diurnal sampling every 5 minutes* suitable not only for climate purposes but also to study atmospheric physics and the behaviour of energetic processes over the observed area but of course not globally at the full Earth. Three geostationary satellites equally spaced around the Earth would provide full space-time coverage of the Earth at the equator; more would provide some overlapping and higher latitude coverage.

This requires international cooperation.

ERB instruments with high spatial resolution



Both kind of observations, *geostationary and polar are complementary* in particular over the poles, and for the purpose of comparing data taken simultaneously but without the capability to really identify what instrument provides the most accurate measurement. The wish is of course that at least the measurements agree but this is unfortunately not a sufficient condition of accuracy.

The instrumentation used depends of course of the observation orbit. ERBE and CERES have constantly been operated on polar satellites with *scanning telescopes (two mirrors)*, moving cross-track or along the orbit for improved reflection directional measurements; some satellites operate with a second scanner rotating continuously on its axis. This is highly useful for the determination of angular distribution models (ADM). On the ERBE satellite flat

plate radiometers (*no mirror*) have been used providing directly at the local satellite altitude reflected and emitted fluxes whose variability diminishes with the altitude of the satellite.

From a geostationary orbit the objective is to make successive image measurements of total radiances separated in solar reflected and thermally emitted components.

If the geostationary satellite is three axis stabilised the situation is easier than with a spin stabilised satellite like MSG where observation time is lost. An *additional mirror in counter rotation* to freeze momentarily the scene and *faster response time sensors* are required.

The *target location identification* can also become difficult due to spin axis variations caused by the imperfect parallelism of the GERB (five mirrors) rotating axis to the satellite spinning axis (associated in time with fuel consumption) that needs to be as accurate as possible. The jitter on the “start of line pulse” generated by the imager is the most bothering as it can not be corrected.

From the altitude of the satellite the measurements are total radiances. For the same spatial resolution the angular response of the telescope is a critical characteristic (*point spread function*) more difficult to achieve for geostationary platforms than for low Earth orbiters because of the distance to the Earth. In addition note that GERB rotates at the rate of 100 revolutions per minute and is submitted to a force of 16 G.

In all cases the instrumentation introduces *spectral absorptions* due to the use of mirrors and imperfect black sensor surfaces, with eventual *aging on orbit*. In view to be able to correct the mirror filtered radiances to unfiltered, the location and *exact identification of the target* (type and cloud proportion) is required with its *spectral directional reflectivity and emissivity*. Detailed and *accurate spectral characterisation* of the instrument on the ground is thus imperatively required, as well as the capability to *monitor spectral and sensitivity aging in space*.

Finally the last but not least difficulty to overcome on the ground ,is the conversion of the measured and spectrally corrected radiances (unfiltered radiances) to total solar and thermal irradiances (fluxes) at the top of atmosphere level (TOA). For this it is required to know the particular reflective characteristic or bidirectionnal reflection function (BDRF) also called *angular distribution model* (ADM) [ERBE, Loeb] of all possible target types function of the scene geometry, the solar zenith angle and the relative position of the

satellite and the target. *Cloud optical depths, cloud phase and cloud cover* are also important to identify. Realizing that these are mostly not homogeneous and not necessarily well represented in the “classical target categories”, the transformation of radiances to irradiances is probably the origin of the largest error in the determination of the outgoing radiation components of the Earth radiation budget.

The identification of the observed targets requires *additional information* provided mostly by imagers flying simultaneously on the same platform like SEVIRI for GERB [Ipe, Ipe2] or MODIS for CERES. The data treatments depend obviously on the footprint of the imager and of the wide band field of view instrument.

Because of the space time sampling problem *different groups* work on the determination of the Earth radiation budget terms. The strategies followed to realise the end product are often different but the results found should be coherent and *all expressed W/m²* units. This requires positive interactions and collaborations, mutual comparisons and constructive interactive analysis of results, all in a true metrological spirit.

To improve the coherence between the observations from the different groups it seems very useful that a large field of view radiometer (flat plate radiometer) be associated to the scanners measuring filtered radiances. This will help to verify the unfiltered radiance to irradiance transformation.

Experience shows that ERB instrumentation needs very careful characterisation and design concern kept independent of launch calendar.

References

Luis Gonzalez, "GGSPS Geolocation Assessment with RGP", Technical Note, 2003, Unpublished.

[BAMS] J.E. Harries et al. (2005):
The Geostationary Earth Radiation Budget Project, *Bulletin of American Meteorological Society*, **86**(7), 945-960, doi:10.1175/BAMS-86-7-945.

[ERBE] Taylor, V. R., and L. L. Stowe:
Reflectance characteristics of uniform Earth and cloud surfaces derived from Nimbus 7 ERB, *J. Geophys. Res.*, **89**, 4987– 4996, 1984.

[Loeb] Loeb, N.G., et al., 2003:
Angular distribution models for top-of-atmosphere radiative flux estimation from the Clouds and the Earth's Radiant Energy System instrument on the Tropical Rainfall Measuring Mission Satellite. Part I: Methodology, *J. Appl. Meteor.*, 42:240–265.

[Ipe] A. Ipe, N. Clerbaux, C. Bertrand, S. Dewitte, L. Gonzalez (2003): Pixel-scale composite top-of-the-atmosphere clear-sky reflectances for Meteosat-7 visible data, *Journal of Geophysical Research*, **108**(D19), 4612, doi:10.1029/2002JD002771.

[Ipe2] A. Ipe, N. Clerbaux, C. Bertrand, S. Dewitte, L. Gonzalez (2004): Validation and homogenisation of cloud optical depth and cloud fraction retrievals for GERB/SEVIRI scene identification using Meteosat-7 data, *Atmospheric Research*, **72**, 17-37, doi:10.1016/j.atmosres.2004.03.010.

[CERES] Wielicki, B., Barkstrom, B.R., Harrison, E.F., Lee, R.B., Smith, G.L., Cooper, J.E., 1996. Clouds and the Earth's Radiant Energy System (CERES): an earth observing system experiment. *Bull. Am. Meteorol. Soc.*, **77**, 853– 868.